An intuitive graphical user interface for small UAS

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ABSTRACT

Thousands of small UAVs are in active use by the US military and are generally operated by trained but not necessarily skilled personnel. The user interfaces for these devices often seem to be more engineering-focused than usability-focused, which can lead to operator frustration, poor mission effectiveness, reduced situational awareness, and sometimes loss of the vehicle. In addition, coordinated control of both air and ground vehicles is a frequently desired objective, usually with the intent of increasing situational awareness for the ground vehicle. The Space and Naval Warfare Systems Center Pacific (SSCPAC) is working under a Naval Innovative Science and Engineering project to address these topics. The UAS currently targeted are the Raven/Puma/Wasp family of air vehicles as they are small, all share the same communications protocol, and are in wide-spread use. The stock ground control station (GCS) consists of a hand control unit, radio, interconnect hub, and laptop. The system has been simplified to an X-box controller, radio and a laptop, resulting in a smaller hardware footprint, but most importantly the number of personnel required to operate the system has been reduced from two to one. The stock displays, including video with text overlay on one and FalconView on the other, are replaced with a single, graphics-based, integrated user interface, providing the user with much improved situational awareness. The SSCPAC government-developed GCS (the Multi-robot Operator Control Unit) already has the ability to control ground robots and this is leveraged to realize simultaneous multi-vehicle operations including autonomous UAV over-watch for enhanced UGV situational awareness.

Keywords: UAS, UAV, GCS, Raven, Puma, Wasp, user interface, MOCU

1. INTRODUCTION

Tactical UAVs such as the Raven, Puma and Wasp are often used by dismounted warfighters on missions that require a high degree of mobility by the operators on the ground. The current ground control stations (GCS) for the Wasp, Raven and Puma tactical UAVs require two people and two user interfaces – one for basic control of the aircraft from an airborne camera perspective and the other using a third-party map display. Typical in-theater usage is shown in Figure 1, the data displayed on the interfaces is shown in Figure 2.

Figure 1. Two operators controlling a Raven RQ-11. The laptop is used for map-based control while the hand controller is used for manual control. ***Photo courtesy of John Moore/Getty Images***

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Figure 2. The actual displays of the laptop and hand controller.

For the stock GCS, the vehicle operator (VO) uses the hand controller for launching and various manual control modes. The hand controller displays live video from the aircraft with block text overlays. More detailed control is possible via text-based menus. The mission operator (MO) uses the laptop for map-based control of the vehicle, limited to setting parameters of the various waypoints (the waypoints are labeled A, B, C, D, E, L O1, O2, O3 and H). The VO has no map display (video only) but has full control of the vehicle. The MO can display the live video but cannot control the vehicle in any mode other than NAV mode, which is used for waypoint control.

2. STOCK GCS

While it is possible for an operator to complete a mission single-handedly the preferred mode of operation uses two operators. As has been documented in many publications[1,2,3,4] coordinated control of a UAS with multiple operators is difficult and can be the source of mishaps resulting in damage to or loss of the UAV. While the Raven, Puma and Wasp UAVs are much simpler and easier to operate than those identified in the cited works, the issues of coordinated control are still applicable. In addition, the existing GCS, while relatively easy to use, presents several challenges from a user interface perspective. Pamranky[5] found that during a typical ~43 minute mission there were over a thousand instances where the operator was subjected to high workloads.

2.1 Situational Awareness

Manning[4] notes that situational awareness is a leading causal factor in mishaps. For the stock GCS there are several detriments to situational awareness:

- The lack of a map display for the VO. The VO rarely knows the location of the vehicle on a map, which is invaluable in determining not only where the vehicle is but also potential hazards to the UAV.
- Poor heading display (usually displayed as a number rather than as a compass rose, though a blocky compass can be overlaid on the video).
- Poor or non-existent altitude above ground level (AGL) display. This is important for mission effectiveness as well as vehicle safety. AGL altitude can be displayed on the MO screen by displaying the Mission Altitude Control Screen and clicking on a waypoint, at which point the AGL altitude for that waypoint will be displayed for 3 seconds.

- Disorientation when switching view from the handheld controller. The display on the handheld controller is relatively dim so a hood is necessary during daylight. Whenever the VO needs to “de-hood” the change in brightness causes loss of vision for 5-15 seconds. This disorientation period could be crucial if the UAV is being brought in for a manual landing or if the VO needs to move quickly due to a developing situation.

2.2 Hardware

The stock GCS hardware is fairly compact considering it is intended to be used by two operators. However, there are some issues with the hand controller hardware:

- As mentioned above the display screen on the hand controller requires a hood when used in daylight conditions as the screen is too dim to be used otherwise.
- Conversely, the hand controller screen is not night vision goggle (NVG) compatible, so night time operations where NVGs are used become awkward in a way similar to the problems with daytime use.
- Video latency is about 400 milliseconds. This is adequate, but our own tests have shown that this can be reduced by at least a factor of two. This could make some control operations such as camera orientation over a desired point much easier to achieve.
- The majority of GCS hardware is vehicle specific and cannot be used to control other vehicles or used for any other purpose. In addition, upgrading or replacing the GCS with more modern hardware would be difficult or impossible.

2.3 User Interface: Hand Controller

The hand controller for the stock GCS (shown in Figure 2) is a relatively simple device consisting of a video screen with text overlays, a joystick, a toggle switch, a four-way “hat” control and four buttons (two on the front and two on the back). The display in particular is a very simple device; it just displays video from the UAV with textual overlays to display data and implement menus. It has neither a touch screen capability nor any kind of pointing device such as a mouse.

- The graphics capability is limited to what can be displayed with character graphics. For example, the camera field of view indicator is  and the icon for the home waypoint is 
- Because of the limited display room, resolution and graphics capability, the textual displays can be cryptic. For example, the standard display screen has four different textual fields indicating angular measurements for magnetic heading, direction from the home waypoint to the UAV, wind direction, and target bearing, none of which are labeled. A trained operator could discern the meaning of each of these fields from surrounding context but being able to immediately find the desired information requires more cognitive effort than is desirable.
- Camera selection and zooming is awkward. A shift key on the left side of the back of the hand controller must be held in to bring up a camera menu. The menu select four-way switch (also on the left side) is then used to select a camera (front or left) as well as zoom. The zoom selection (there are four fixed levels) is different depending on which camera you are zooming. For the left camera moving the control left cycles through the zoom levels in a fixed order. For the front camera moving the control up cycles through the levels. The down and left motions of the control change the camera filters or turn the cameras off.
- Initial loiter mode selection requires four button clicks to engage, which often results in the desired loiter point not being achieved. Fortunately, re-establishing a loiter point while in loiter mode can be done by double-clicking the Enter button. However, it is unclear which location the vehicle is attempting to loiter around since there is no graphic overlay to display this information on the handheld unit.
- The wind indicator is a simple numeric angle and speed. It is crucial when using automated landing that the final approach segment be aligned into the wind. The landing direction is established by the E and L waypoints and must be positioned such that going from E to L results in the vehicle heading directly into the wind. Crosswind or downwind landings can result in damage to the aircraft as well as poor touchdown point

performance. Unfortunately, it is difficult to translate the numeric value for wind direction into the graphical representation of the E and L waypoints, which increases the likelihood of creating an incorrect landing plan.

2.4 User Interface: Laptop

The laptop runs the DoD FalconView program. This is connected to the GCS via an Ethernet cable that provides status information and video as well as limited control of the vehicle. The FalconView application was never intended to be used for vehicle control (it is primarily a map display and mission planning application), and as a result there are several usability issues:

- The MO (via FalconView) can only control the vehicle when it is in NAV (waypoint) mode. When the MO moves a waypoint a message is displayed indicating that the UAV is being re-routed. This message remains for a few seconds then disappears. However, if the vehicle isn't currently in NAV mode the command will have no effect, but no error message will be displayed. The MO must first verify that the vehicle is in NAV mode via a dense text display in the lower left corner of the map to ensure that the change will have an effect. The VO can change modes at any time and the MO is not notified other than the text display in the lower left corner.
- The graphical heading displayed via an icon on the map shows the course heading of the vehicle while the textual heading on the hand controller shows magnetic heading. These differences are often significant and are exacerbated by windy conditions.
- Waypoint altitudes can be adjusted numerically or graphically in two different dialogs. For maximum mission duration the mean sea level (MSL) altitude should be the same for all waypoints, subject to mission constraints. However, there is no easy way to force all the waypoints to the same MSL altitude, and in fact it is quite easy to inadvertently change the altitudes of the waypoints during other mission planning operations.
- On the graphical waypoint altitude dialog the textual altitudes are only displayed when the user clicks on a waypoint and moves it. This has the side-effect of changing the altitude of the waypoint which may not be desired.
- The above ground level (AGL) altitude can only be displayed on the graphical dialog and is only displayed for a single waypoint at a time, and even then only for three seconds. As with the MSL altitude, the operator must first move a waypoint before the AGL for that waypoint will be displayed.
- In all modes except NAV mode the current altitude can easily be increased or decreased with the throttle control.

3. MULTI-ROBOT OPERATOR CONTROL UNIT

All of the shortcomings of the current GCS can be addressed using a laptop-based GCS with the appropriate software. The Space and Naval Warfare Systems Center Pacific has been developing the Multi-robot Operator Control Unit (MOCU) software since 2001 with the intent of making it of use on any robotic system regardless of the domain in which the robot operates.

MOCU was designed to be completely modular. This is especially true for the user interface. As described in Powell[7], MOCU was designed in particular to focus on making the user interface as flexible and programmable as possible, with an eye toward developing game-like interfaces that current and future unmanned vehicle operators will be accustomed to. The rest of this paper describes how MOCU was used to implement a better user interface to the Raven-class of UAVs.

In this instantiation of MOCU a ruggedized laptop (similar to that of the stock GCS) is used, but the hand controller has been replaced with an Xbox 360 gamepad, something the operators are likely to already be very familiar with. The stock GCS radio is used, however the "hub" is not needed, thus saving significant weight and reducing complexity.

3.1 Single screen, single operator

The first task in improving the user interface was to put all the functionality onto a single screen. This means the display must be able to show both live video from the UAV as well as maps and map-related data. The screen shown in Figure 3 illustrates the how the video is displayed. The video is the background for the data on the display (more on that below). Starting with the left side, going from top to bottom, there are indicators for current mode (MAN indicates manual

mode), camera selection and zoom level (left camera, narrow, meaning next to highest zoom level), and an altitude tape, with the vehicle's current altitude shown in the black box with white text. Because a touchscreen is used the mode and camera indicators can also be touched to bring up menus to select different modes or cameras. This means that at most two actions are required to change either the UAV mode or the camera and zoom level.

The upper right corner of the display shows the vehicle battery and communications status. On the stock GCS the operator must memorize critical voltage levels to recognize when the battery is getting low, while MOCU uses a graphical icon very similar to what users are accustomed to seeing on their cell phones. This area of the display is also used for bringing up more detailed menus (the gear icon) as well as a map orientation indicator (the map will have the ability to be rotated arbitrarily to make situational awareness easier). Along the right edge is an airspeed tape as well as a graphical indicator depicting throttle setting (only shown for 3 sec. after a throttle change).

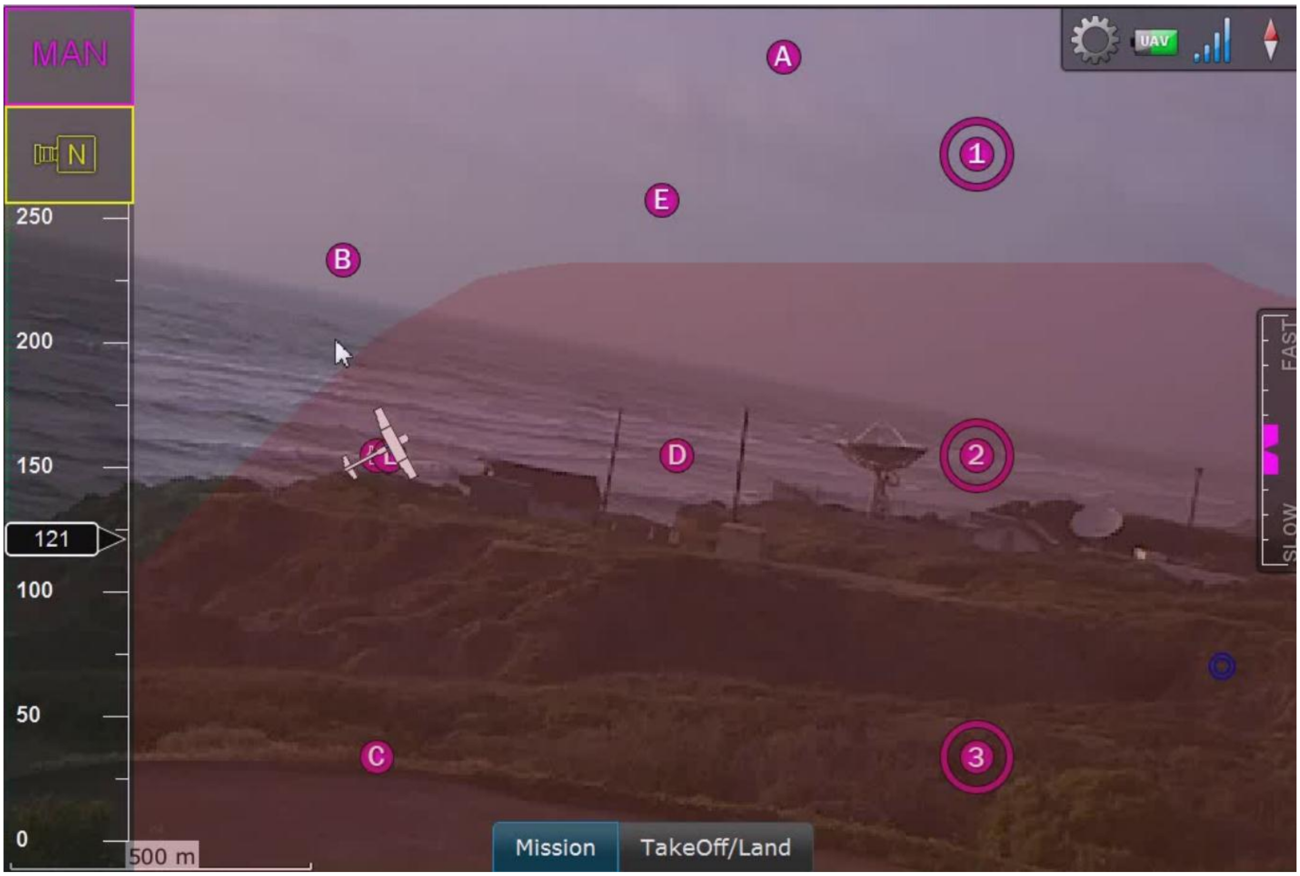

Figure 3. MOCU screenshot showing how video is displayed.

The A, B, C, D, E, and L icons are the pre-defined waypoints while the 1, 2 and 3 icons with the circles are the orbit waypoints. The plane-like icon represents the position and orientation of the vehicle itself. Note that these are all map-centric not video-centric (this will be explained below). Finally, there is a red shading over most of the display. This is a profile of the elevation directly in front of the vehicle. This is a safety-related feature unique to MOCU. Under normal (safe) flight operations the red area is not visible; it only becomes visible when there is a potential terrain conflict. In this particular case the vehicle was pointed toward a hill and if the vehicle were to fly in that direction without an increase in altitude it would contact the ground.

Figure 4 shows virtually the same screenshot, but with the background changed to show the map. The vehicle icon and the various waypoints now make a little more sense since they are directly related to the map. The important user interface feature to point out here is that the same waypoint and vehicle location data is present both on the map *and* on the video, so that when the user toggles between the two screens these icons remain in the same location. This gives the

operator better situational awareness for where the vehicle is relative to the GCS and the waypoints, while still displaying the video, which is used more frequently by the operator during a mission than the map.

The screen of the laptop is sufficiently bright alleviating the need for a hood, thus taking their eyes away from the screen to view the UAV directly is no longer a detriment to their eyesight. In addition, since both video and map data are available on the same screen there is no need to de-hood to view the map; a simple button click suffices. Laptops that are compatible with night vision goggles are available so night time covert operations are now possible as well.

Figure 4. MOCU screenshot with a map background. Note that other than the background, the display is the same as that shown in the video screenshot above.

3.2 Other user interface features

Several other usability improvements have been made, including:

- Single button click to establish a loiter point
- At most two touches (or mouse clicks) to change from any camera mode or zoom level to any other mode or zoom level
- The altitude command can be changed in all autopilot modes (including NAV) via the throttle control. The altitude command is displayed graphically on the altitude tape.
- Video latency reduction from 400 milliseconds to 200 milliseconds. This may be helpful in establishing more precise loiter points.
- Color coding is used to indicate common GUI features. For example, autopilot-related items such as UAV mode, waypoints, and commands are magenta, while video-related items are yellow.

3.3 Mission planning improvements

As previously mentioned there are some eccentricities with the waypoint altitude display of the FalconView-based mission planner of the stock GCS. The equivalent waypoint altitude planner for MOCU is shown in Figure 5.

Figure 5. MOCU waypoint altitude mission plans show AGL in the text box while the MSL of the waypoint is shown in the altitude tape on the left.

The planner is split into two different types, one for mission-related operations (waypoints A – D, the orbit waypoints, and the rally altitude), and takeoff and landing. The screenshot in Figure 5 is for mission planning. The MSL of each waypoint can be seen relative to the altitude scale on the left, but more importantly the AGL altitude is shown both graphically (the green terrain below each waypoint) as well as textually in a box below each waypoint. Missions often require that a minimum ground clearance be maintained which is easy to do here, whereas it is tedious with the stock GCS.

Figure 6 shows the takeoff and landing planner. In the stock GCS the mission and takeoff/landing planners are all combined into one display. However, MOCU renders the planners as separate windows making the display less cluttered and more usable during these distinct phases of flight.

Figure 6. Mission planner for takeoff and landing. For takeoff the relationship between the launch point (the home icon) and the first waypoint (A) are most important, while for landing the D, E and L waypoints are most important.

One last mission planner difference is shown in Figure 7. If the user clicks and drags along the right edge of the waypoint window all the waypoints are locked to the same MSL altitude. If the waypoints are left at different MSL altitudes the UAV is constantly climbing and descending, thus decreasing overall mission time.

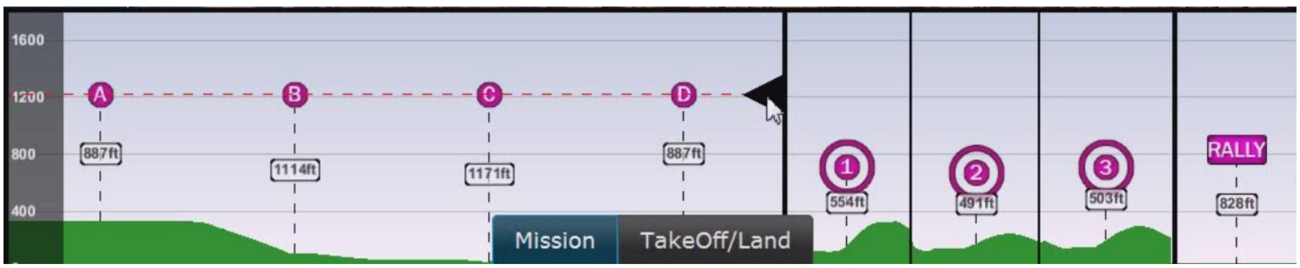

Figure 7. MOCU makes it easy to set all the waypoints to the same MSL.

4. FUTURE WORK

Many improvements are planned in the near term:

- Graphical display of wind speed and direction. The direction in particular will help with aligning the E and L waypoints so that the vehicle lands into the wind to minimize the possibility of damage and increase touchdown performance.
- Graphical range and bearing from the home waypoint to the vehicle. This indicator will be color coded red, yellow, or white to indicate if the remaining battery capacity is sufficient to return home given the current range and winds aloft.
- 3D fly/no fly zones. MOCU already has the capability to draw and display fly/no fly zones, but these need to take minimum and maximum altitudes into account. The altitude extents of zones will be depicted on the altitude tape and mission profile displays for quick reference during flight and mission planning stages respectively.
- MOCU has the ability to rotate maps to an arbitrary angle. By implementing a user interface control for this it will improve the operator's situational awareness. The typical mission requires flying in pretty much a straight line to a particular area then flying around that area. By rotating the map so the operator is at the bottom and the desired operational area is at the top, placement of waypoints becomes more intuitive and situational awareness can be more easily maintained.
- A camera pointing indicator (CPI) will be added to the video display. This will show in the video the location the vehicle is currently being commanded toward (for waypoints) or circling (for loiter). In addition, the operator will be able to drag this icon to the desired point. This should significantly ease the difficult job of establishing the desired loiter point.

- Telestrator-like (aka “John Madden”) annotations to both the map and video screens. This is a feature many users have requested, which would allow them to drop points on the screen and draw lines to make notes or communicate to other operators desired actions. In addition these annotations can be used to make range, distances and angular measurements on both the video and map screens.
- Users will be shown how the MOCU-based GCS operates and their feedback will be used to improve the system or add desired features.
- User performance will be measured using both a simulator and actual flights. This will allow a direct usability comparison between the stock and MOCU GCSs.

5. SUMMARY

The stock GCS for flying the Raven-class of UAVs is compact and relatively easy to learn. However, it has some drawbacks:

- Two person operation (preferred, though not required)
- Two distinct, dissimilar user interfaces to achieve full vehicle control and mission planning
- Poor situational awareness due to the need to use a hood to view the hand controller display
- Cryptic displays due to character-oriented graphics

A MOCU-based software GCS has been developed that addresses all these shortcomings as well as additional usability and safety improvements. MOCU allows a single user to easily control the UAV for the entire mission including launch, execution, and landing (either manually or automatically). Because everything is done through a single user interface and single display there is no need to switch from the hand controller to the laptop and back, eliminating the risk of disorientation caused by lighting differences.

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